PROBABLE AIRCRAFT "TRIGGERING" OF LIGHTNING IN CERTAIN THUNDERSTORMS

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ABSTRACT

Three aircraft have been used to study the lightning and related cloud physics properties of Florida thunderstorms. The average probability of a lightning strike to the storm penetration aircraft was 0.021, based on the ratio of aircraft strikes to total number of strikes during penetration periods. On 2 exceptional days, the probability increased to 1.00 and 0.50. These storms were found to be in an early dissipating stage. The results appear to confirm the suggestion of L. P. Harrison that an aircraft may act to initiate streamers and lightning discharges by suddenly augmenting the field in a localized region in the storm. This effect is most likely to occur shortly after the storm activity has diminished to the point where natural streamer formation is difficult.

1. INTRODUCTION

Lightning strikes to aircraft frequently cause minor structural damage, occasionally cause moderate damage, and in rare instances have been implicated as a probable cause of destruction of the aircraft. The question of whether an aircraft can initiate or attract a lightning discharge has been raised from time to time. Harrison [1] from consideration of more than 150 reported incidents found that a great majority of the discharges occurred while the aircraft was definitely in cloud. Of these, 45 percent reported lightning seen before or after the discharge. Fifty-five percent indicated no other natural lightning was observed. He suggested that the field distortion or augmentation created by the presence of the aircraft may raise an initially high, but sub-critical potential gradient to the level where breakdown occurs at or near the aircraft. If conditions are suitable, the streamer could then continue to propagate between charge centers and a discharge would occur.

Recent thunderstorm electrification research flights have provided data in general agreement with the above suggestions. These studies of Florida thunderstorms have been conducted in 1964 through 1966 by the AFCRL Cloud Physics Branch in cooperation with the Aeronautical Systems Division, AFSC; Sandia Corporation; and the Federal Aviation Administration.

Three well instrumented aircraft were used in the program. A C–130 measured electric fields and radar cross-sections from positions at medium altitudes outside the storms. A U–2 aircraft obtained photographic, infrared, and electric field data from above the storms, and a F–100F penetrated the storms to obtain turbulence, electric field, and lightning current waveform information. Additional radar cross-sections were obtained from Air Defense Command, Air Weather Service, and Weather Bureau radar stations in Florida.

Analysis of the 1965 data is in progress. The detailed examination of lightning events on different days and at different stages of the storm development as illustrated in this paper suggests that the aircraft effect on lightning ranges from very small to probably decisive. Elements from the analyses of three periods of operation are used to demonstrate the range of effects encountered. These are selected from 205 storm penetrations covering a distance flown of 4,100 n.mi. in thunderstorms. The F–100 aircraft was struck by lightning at least once during 31 of the penetrations, or on 15 percent of the storm passes.

2. PROBABILITY OF IN-STORM LIGHTNING STRIKES

A discrete binomial distribution was used as the statistical model to estimate the probability of lightning strikes on each separate mission:

$$P(x)=\binom{n}{x} q^{(n-x)} p^{x} \text{ for } x=0, 1, 2, 3, \ldots, n. \qquad (1)$$

For the ith mission, n_i was taken as the total number of lightning strikes counted from the storm, or total number of "trials" by the storm, and x_i was taken as the number of hits on the aircraft, or successful trials.

Each success was well documented by the instrumentation and pilot remarks. The total number of flashes was harder to obtain for several reasons. The spatial pattern of electrostatic field fluctuations within the storm frequently appears on flight records as a change at about the same rate as a distant lightning field change. In addition, the sensitivity of the F–100 system was somewhat lower than that of the peripheral aircraft. For these reasons total counts were made whenever possible from records of an aircraft outside the storm. These records usually indicated distinctive field changes with each lightning flash. The present best estimate for the lightning counts is

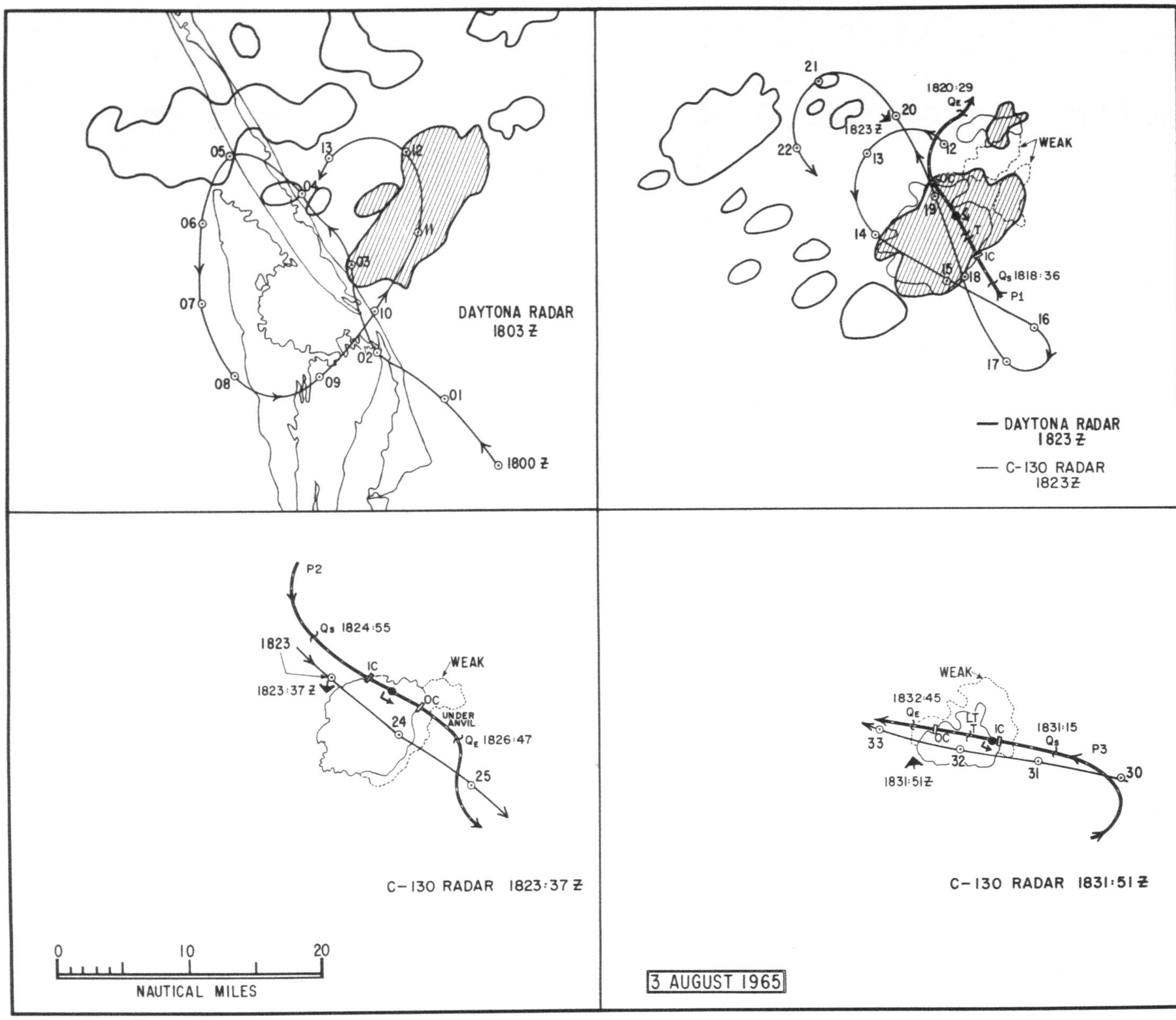

FIGURE 1.—Sequential radar cross-sections and aircraft tracks, August 3, 1965.

TABLE 1.—*Thunderstorm penetrations, lightning counts, and strike probabilities*

Date 1965	x_i	n_i	$p=x_i/n_i$	Date 1965	x_i	n_i	$p=x_i/n_i$
July 22	0	14	0.0000	August 11	2	34	0.0589
23	1	58	0.0172	11 (Flight 2)	3	69	0.0435
26	3	58	0.0518	12	1	2	0.5000
29	0	1	0.0000	12 (Flight 2)	2	147	0.0136
30	0	4	0.0000	16	0	24	0.0000
August 2	1	90	0.0111	17	0	20	0.0000
3	3	3	1.0000	18	0	24	0.0000
3 (Flight 2)	1	74	0.0135	19	0	90	0.0000
4	0	12	0.0000	19 (Flight 2)	1	107	0.0094
5	0	16	0.0000	20	0	103	0.0000
6	3	79	0.0380	23	2	121	0.0165
9	2	106	0.0194	24	3	46	0.0653
9 (Flight 2)	3	125	0.0240	25	0	26	0.0000
10	2	101	0.0198	Total	33	1,554	

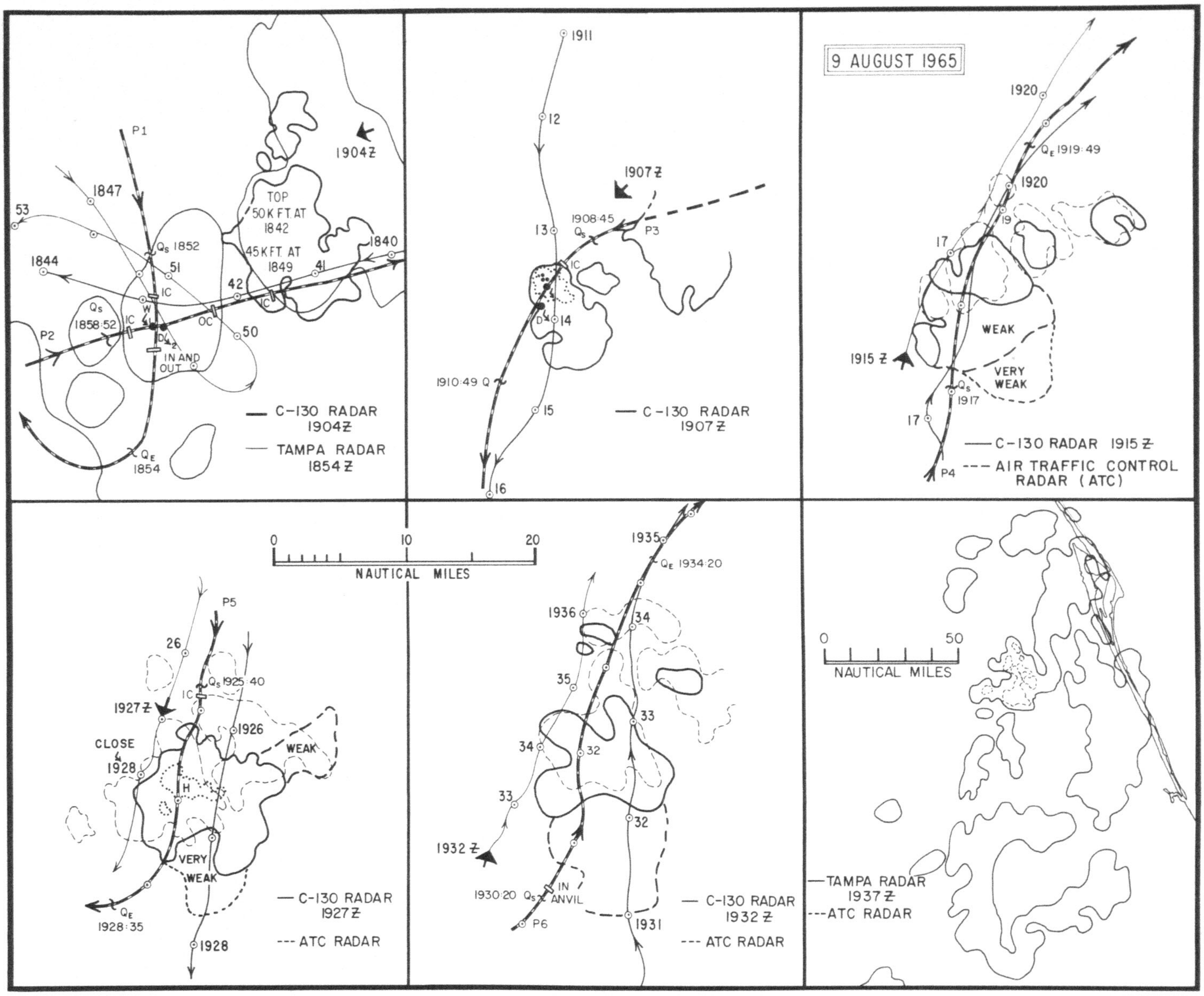

FIGURE 2.—Sequential radar cross-sections and aircraft tracks, August 9, 1965.

given in table 1 together with the maximum likelihood estimate $p_i=x_i/n_i$. The total count is believed to be correct to within ± 20 percent and will be further refined when all flight tracks and timing have been verified.

An examination of table 1 suggests that unusual probability values occurred on the first flights of August 3 and August 12. The observed probability for the entire data period was $p=33/1554=0.021$. On these 2 days, the values of p were 1.00 and 0.50 respectively. If $p=0.021$ is taken as an approximately correct value for the average Florida thunderstorm, the cumulative probability of the unusual events occurring from the average storm can be found from tables by Weintraub [2] as $P=0.00000926$ and $P=0.041559$ for August 3 (3 of 3) and August 12 (1 or more of 2). In comparison, the probability of obtaining two or more strikes out of 100 trials as was approximately the case on August 9, is $P=0.62338$. These results appear sufficiently unusual to warrant documentation of the storm properties on these 2 days, and a comparison with the more "normal" situation occurring on August 9.

3. DETAILED STORM FEATURES

Composite PPI radar cross-sections and the aircraft flight track data for the three thunderstorm cases are shown in figures 1 through 3. The F-100 flight track is depicted by the heavy lines in each figure. The symbols associated with the F-100 paths are defined as follows:

Q_S, location and time aircraft skin charging began
Q_E, end of period of aircraft charging
H, hail encountered
T, turbulence; LT T, light turbulence
W, intense rain
D⦣, distant lightning
⦣, strike to aircraft
IC, OC, pilots comment for in and out of cloud, based on visual observation

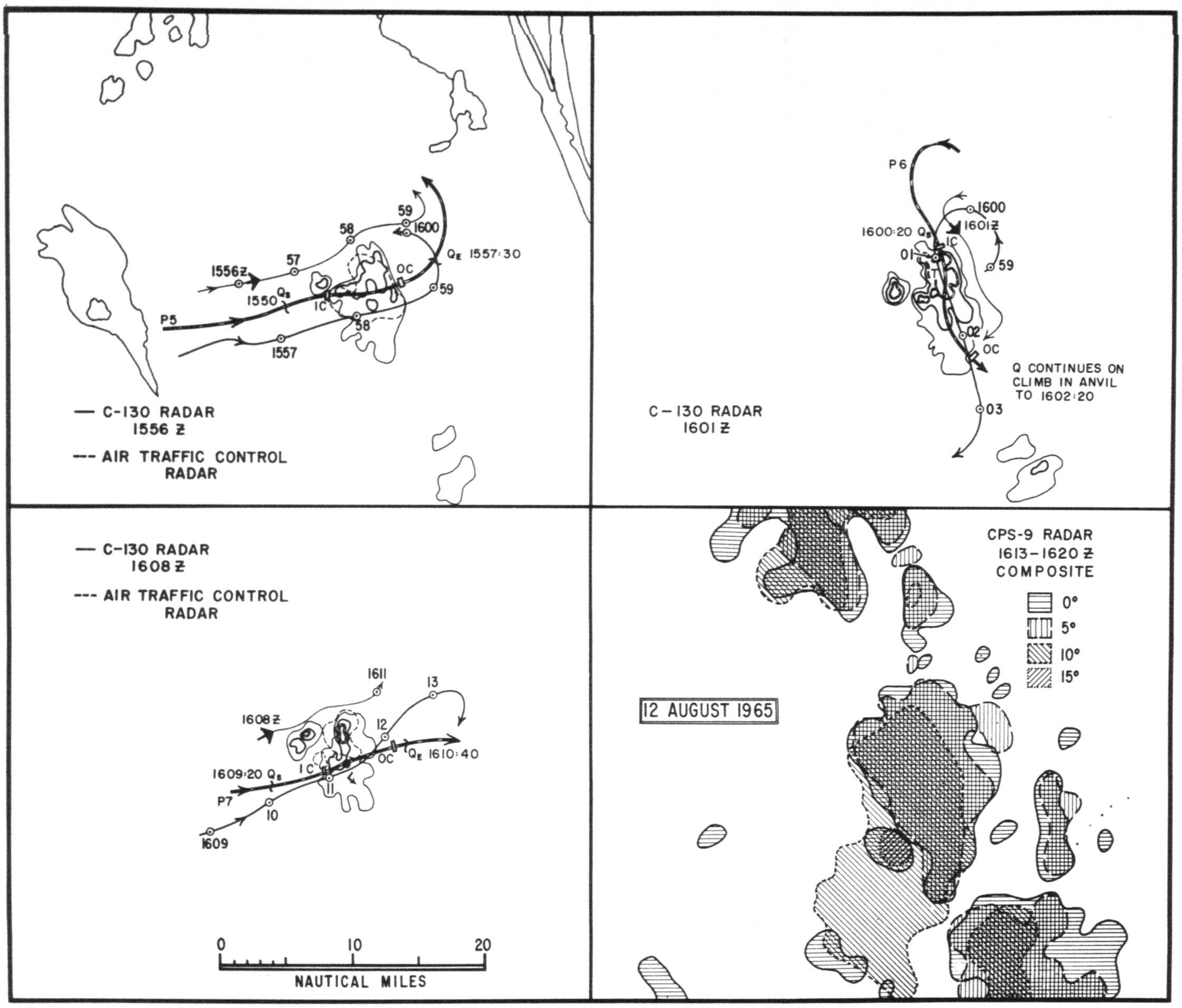

FIGURE 3.—Sequential radar cross-sections and aircraft tracks, August 12, 1965.

The thin line showing apparent flight through the storm represents the U–2 overflight trajectory. The C–130 flight track is omitted from figure 1 and shown as a thin line on the other figures. Positions of the C–130 at the times of the airborne radar sections are indicated by the solid triangular shapes. All time is shown as GMT.

The storm of August 3 had been electrically active during the early overflights by the U–2 from 1800 to 1812. The average lightning count rate decreased steadily as shown by figure 4. The airborne radar cross-section shown in figure 1 was decreasing in size during the second and third penetrations. The Tampa and Daytona Beach Weather Bureau WSR–57 radars also indicated a weakening and dissipation of the storm echo by the time of the last pass. The Daytona echo from this storm is shown cross-hatched in the upper left and right of figure 1. Unusually good agreement of the airborne and ground radar echo size and shape is shown in the upper right of figure 1. This is an additional indication that no intense precipitation was present at this time. The project UHF Monitor conversations confirm the impression that this storm had definitely passed its period of peak activity and was falling apart. It is interesting to note that this storm was totally over water during its growth and dissipation. Whether this feature was significant in relation to its lightning strike behavior is not known.

The photographic and electrostatic field records of the lightning strike events are shown in figure 5. Traces directly underneath the field data are UHF radio, VHF Atlantic Missile Range Time Code, internal time code and event marker. A heavily filtered, rear-looking, wide angle camera mounted in the canopy of the aircraft was

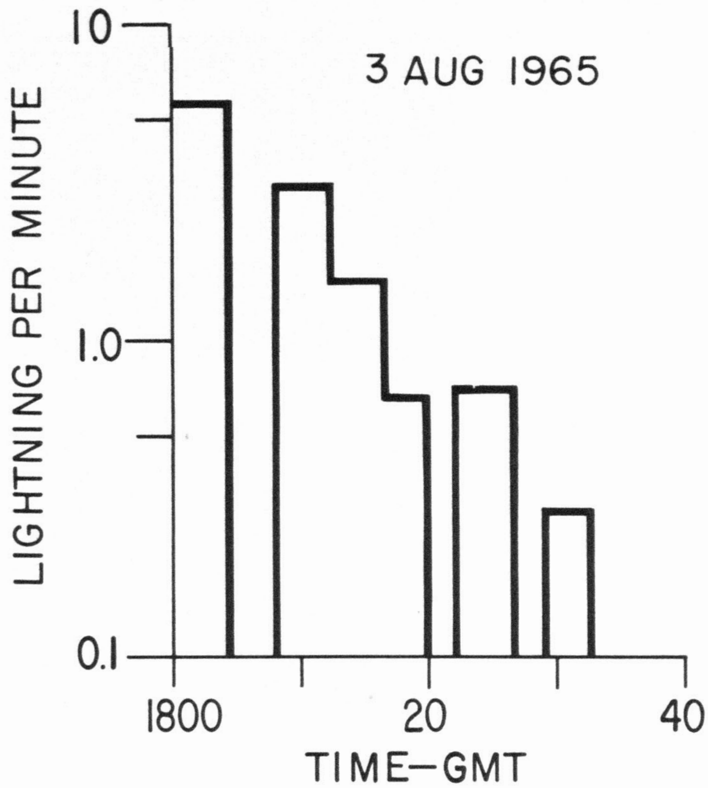

FIGURE 4.—U–2 lightning count rate, August 3, 1965.

TABLE 2.—*Summary of lightning event data*

Date (1965)	Pass	Aircraft charge field change (v./cm.)	Horizontal field change (v./cm.)	Vertical field change (v./cm.)	Maximum current (a.)
August 3	1	−1970		−3610	8700
	*2	−1510	+340	−1730	2700
		+1830	−1740		
	3	+2400	−150	−1480	2800
9	1	−1640	+2940	−1030	4600
	3	−1780	+3500	+290	
12	*7	+680	−360	−1670	5800
		+1640	+360	+1500	
		+2050	−1460	+670	

*More than one listed value indicates significant individual partial discharges.

used to photograph the wing and rudder area. The electric field components were measured with a field meter system generally similar to those described by Waddel et al. [3] and Clark [4]. A real time analog computer on the aircraft was used to separate external field components from the effects of aircraft charge. E_y indicates the horizontal component in the wingspan direction and E_Q is a field with magnitude proportional to the charge on the aircraft and the same polarity as the aircraft charge. Data were recorded on magnetic tape and oscillographic recorders. The field change magnitudes and lightning currents for this and the other storms under discussion are listed in table 2. These fields are indicated in terms of the equivalent calibration fields on the sensors or incident fields at the fuselage and wingtip measurement locations. To approximate the natural field change, the horizontal component should be reduced by a factor of about 8.8 and the vertical component should be reduced by about 1.1. The field magnitudes shown are in good agreement with the Gunn [5] measurement of an incident field of over 3000 v./cm. during a strike to a B-25 aircraft obtained in 1944. The peak currents and vertical field change were lower on strikes 2 and 3 than they had been on the first strike. The maximum current of the 1965 data period was an off-scale value in excess of 12,000 a. The maximum field was 3900 v./cm. This indicates that the first strike on August 3 was one of the larger encountered in the test series.

The storm of August 9 as shown in figure 2 was a vigorous nearly stationary system that was increasing in size during the series of six penetrations. The lightning count rate varied from 5 per min. on pass 1 to nearly 10 per min. on pass 3, and down to about 7 per min. on passes 4 through 6. Considerable turbulence, large liquid water concentrations, and some hail were encountered at 29,000 ft. in the storm. In spite of the generally high level of electrical activity, the aircraft was struck only twice, resulting in a low probability of a strike for any individual try. The number of trials was so large however that the probability of at least one strike during the continuing exposure to the storm was very high. This storm seems to be an example of the situation where the aircraft has little to do with initiating lightning. Many charge centers were active and the storm had numerous opportunities for natural streamer initiation.

The storm of August 12 was a marginally active storm, exhibiting very low count rates. The radar cross-sections from airborne and air traffic control radars shown in figure 3 indicated a weakening structure with time. This was confirmed by the UHF conversations. The Patrick AFB CPS–9 radar continued to indicate a much larger and well-defined cloud structure than the other radars, suggesting the maintenance of large numbers of rather small particles in the cloud.

The relative simplicity of this cloud is useful in demonstrating some of the types of cloud physics data that have been obtained in this program. In figure 6 the U–2 overflight vertical electric field and infrared cloud topography representation are shown superimposed with the F–100 charge, field components, and acceleration record on a computer linearized RHI echo plot of the storm. The 1715 GMT Cape Kennedy sounding indicated a tropopause temperature of −70.7° C. at 50,000 ft. true altitude (48,200 ft. pressure altitude) in good agreement with the −72° C. IR cloud minimum temperature. The U–2 altitude was up to 52,600 ft. (51,000 ft. pressure altitude) on this pass suggesting that the visual cloud tops were at or a little above the tropopause level. The additional IR cloud features shown at the southern end of the storm were clouds not included in the RHI echo linearization. This pass of the F–100 was made at 15,000-ft. pressure altitude (16,000-ft. true altitude). It shows considerable turbulence but no significant lightning activity. Aircraft charging was a generally weak negative charge with a small region of positive charging shown at the 23-n.mi.

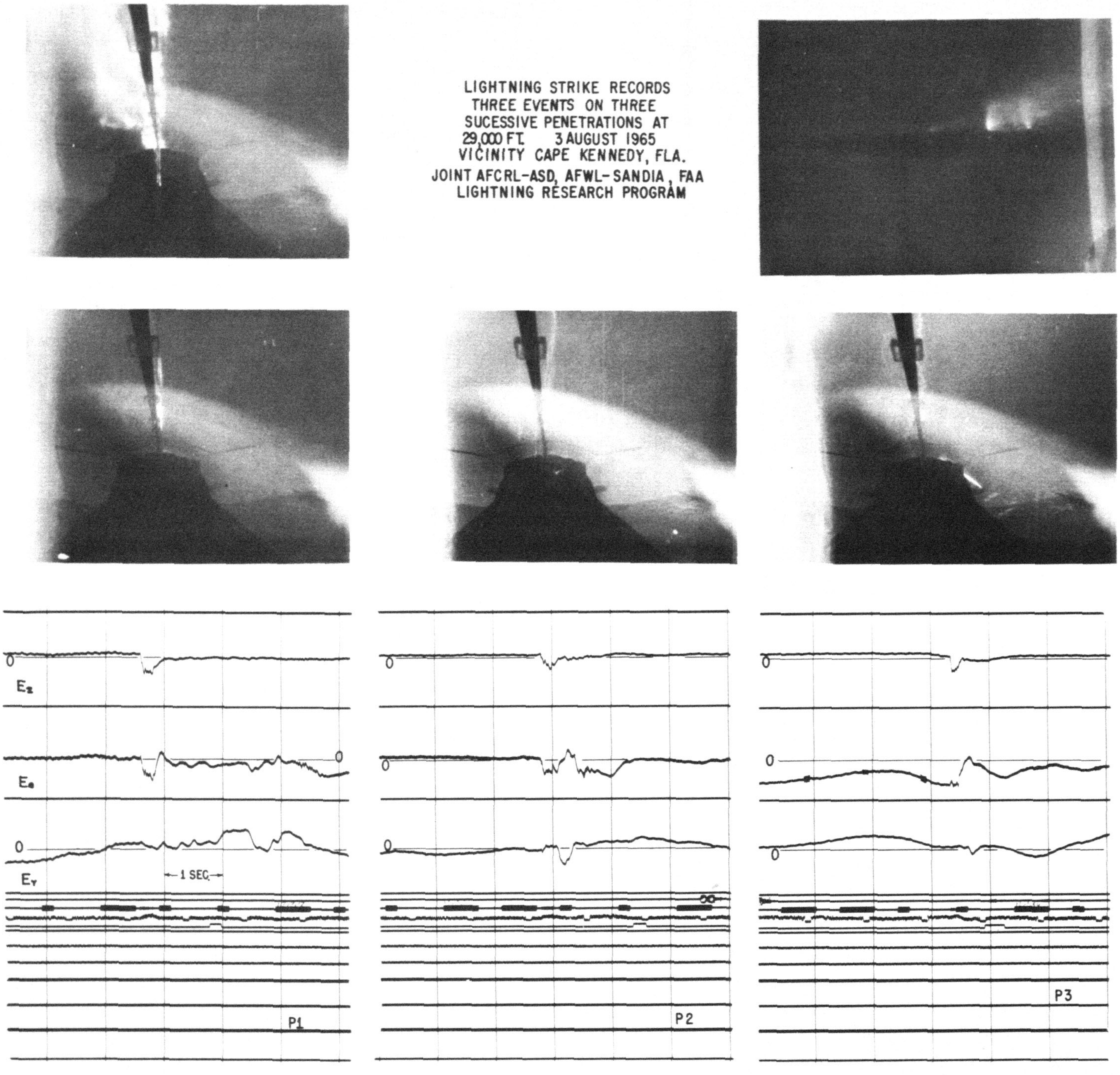

FIGURE 5.—Lightning strike photographs and electric field transient records, August 3, 1965.

radial from Patrick AFB. The vertical field component can be interpreted as resulting from a net negative charge above the aircraft in the storm, with a reversal to positive charge above as the aircraft came out under the anvil. The U–2 field measurement shows definite smooth polarity changes and a field of significant amplitude above the storm. No lightning transients were observed.

Pass 7 was from SW to NE at a pressure altitude of 27,000 ft. The F–100 data for this pass shown superimposed on the IR contour plot along this heading in figure 7. The small amplitude of the U–2 field, in contrast to the value for pass 6, the 7° C. warmer IR top temperature, and the much smoother accelerometer trace suggest that the storm had weakened. The F–100 aircraft charge trace shows a short positive nose, followed by a short period of intense negative charging just prior to the lightning strike. The strike, as indicated on the vertical field trace, resulted in a rapid field recovery in the vicinity of the F–100. This can be compared with the U–2 field record, which indicated a very slow recovery curve.

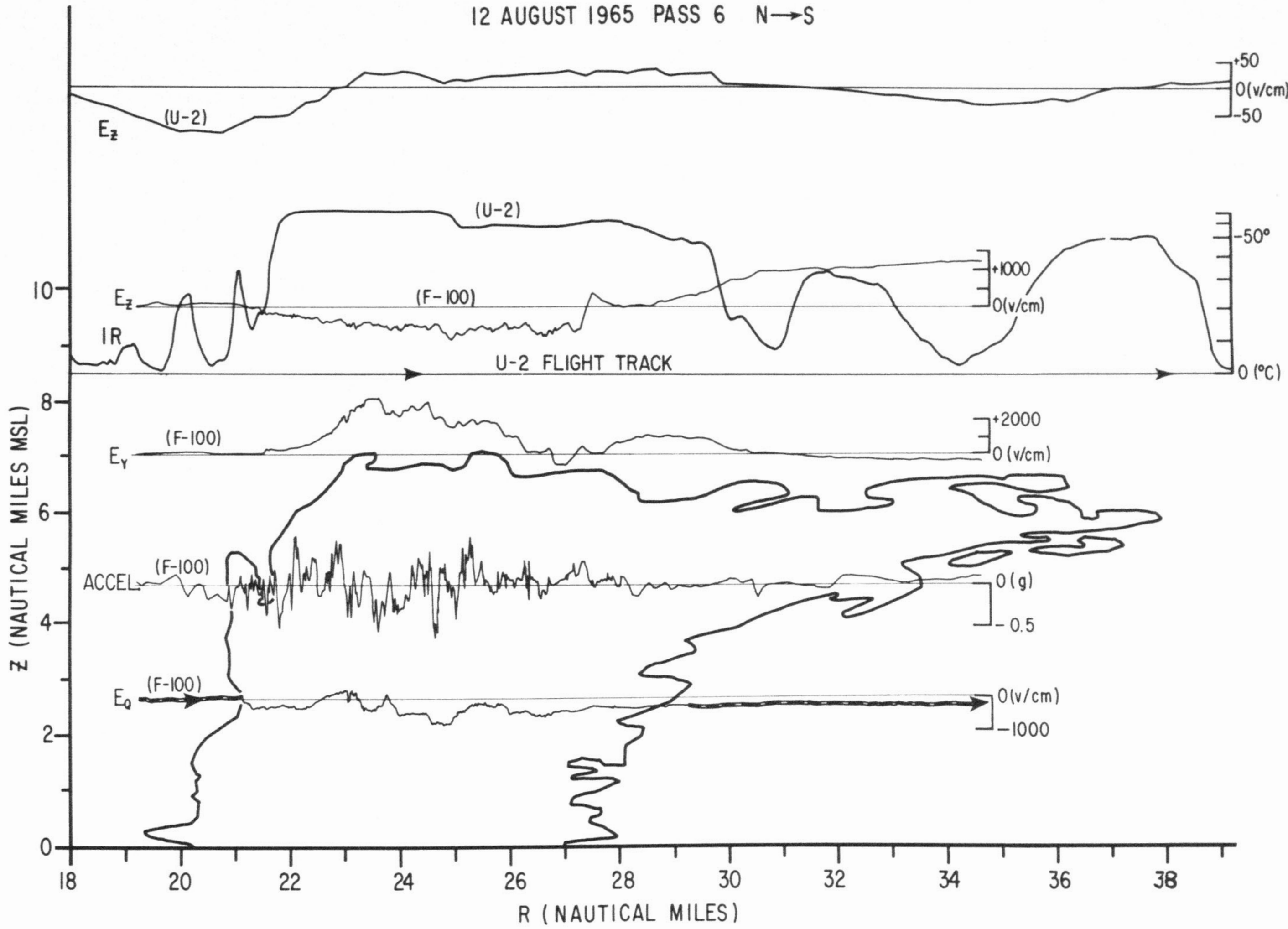

FIGURE 6.—Composite radar and flight data cross-section, pass 6, August 12, 1965.

The instrumental time constants for the two aircraft field measurement systems are the same. Therefore the difference in behavior represents a physical effect.

The phenomenon of encountering small, intense negative charge pockets was rather frequent at altitudes of 25,000 to 29,000 ft. These encounters sometimes resulted in lightning and sometimes did not. It is not necessary to intercept such a pocket to experience lightning. An example can be seen from reference to the E_Q traces of figure 5. The first two strokes occurred when the aircraft was only slightly charged. The third occurred in a condition of strong negative aircraft charging.

4. CONCLUSIONS

The data presented suggest that thunderstorms, in their early stages of dissipation, retain sufficiently large charge centers to account for one or more lightning discharges if a suitable means of initiating a streamer becomes available. It is likely that an aircraft entering a storm in this condition will act to "trigger" a lightning discharge. These clouds may have little turbulence and no distinctive echo pattern on a typical Air Traffic Control radar. In normal IFR flight operations in regions with thunderstorms merged with showers and cloud decks, the routine radar avoidance of the presently most active storm portions may readily lead to flight through a decaying storm and the possibility of an isolated lightning incident to the aircraft.

ACKNOWLEDGMENTS

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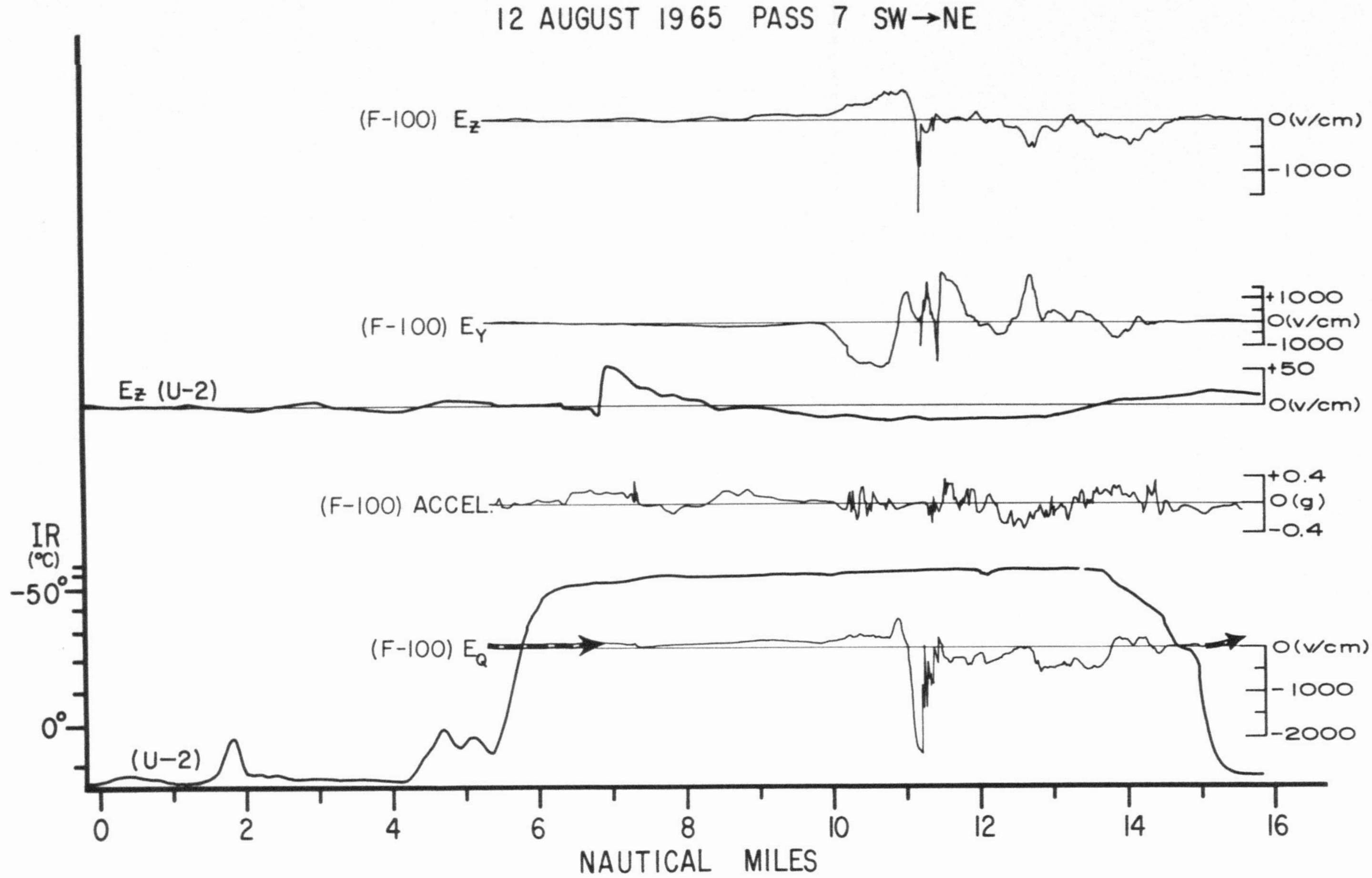

FIGURE 7.—Flight data cross-section and lightning strike transient, pass 7, August 12, 1965.

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